Phenomenology of the Flavor–Asymmetry in the Light–Quark Sea of the Nucleon

M. Glück and E. Reya

Universität Dortmund, Institut für Physik,
D-44221 Dortmund, Germany

Abstract

A phenomenological ansatz for the flavor–asymmetry of the light sea distributions of the nucleon, based on the Pauli exclusion principle, is proposed. This ansatz is compatible with the measured flavor–asymmetry of the unpolarized sea distributions, $\bar{d} > \bar{u}$, of the nucleon. A prediction for the corresponding polarized flavor–asymmetry is presented and shown to agree with predictions of (chiral quark–soliton) models which successfully reproduced the flavor–asymmetry of the unpolarized sea.

The flavor–asymmetry of the light–quark sea in the nucleon has attracted a lot of attention and many attempts were undertaken to explain the origin and calculate its magnitude (e.g., Ref. [1] and references therein). In the present article we study this issue inspired by the suggestion [2] that this asymmetry is related to the Pauli exclusion principle ('Pauli blocking').

Our proposed implementation of this idea is summarized by the phenomenological ansatz for the unpolarized and polarized antiquark distributions

$$\bar{d}(x, Q_0^2)/\bar{u}(x, Q_0^2) = u(x, Q_0^2)/d(x, Q_0^2) \tag{1}$$

and

$$\Delta\bar{d}(x, Q_0^2)/\Delta\bar{u}(x, Q_0^2) = \Delta u(x, Q_0^2)/\Delta d(x, Q_0^2)\,, \tag{2}$$

respectively, with Q_0^2 being some low resolution scale, e.g., the one in [3, 4]. These are our basic relations for the flavor–asymmetries of the unpolarized and polarized light sea densities which imply that $u > d$ determines $\bar{u} < \bar{d}$, etc. This is in accordance with the suggestion of Feynman and Field [2] that, since there are more u- than d–quarks in the proton, $u\bar{u}$ pairs in the sea are suppressed more than $d\bar{d}$ pairs by the exclusion principle. It should be emphasized that our suggested regularity in (1) is entirely of <u>empirical</u> origin, and our anticipated relation (2) has of course to be tested by future polarized experiments. Both relations require obviously the idealized situation of maximal Pauli–blocking and hold approximately in some effective field theoretic (mesonic, bag and chiral) models [1] as we shall see below.

In Table I we present $\bar{d}(x, Q_0^2)/\bar{u}(x, Q_0^2)$ calculated according to Eq. (1) from the (fitted) d, u input distributions of GRV98 [5], as compared to the actual fitted values of this ratio. The good agreement lends support to the phenomenological ansatz in Eq. (1) and thus also to the experimentally so far unknown polarized antiquark flavor–asymmetry implied by Eq. (2). The predictions for $\Delta\bar{d}/\Delta\bar{u}$ according to Eq. (2) are shown in Table II utilizing the most recent LO AAC [6] distributions $\Delta u(x, Q_0^2)$ and $\Delta d(x, Q_0^2)$ which

compare favorably with the predictions of the relativistic field theoretical chiral quark–soliton model [7] for $\Delta\bar{d}/\Delta\bar{u}$, as well as with a recent analysis based on the statistical parton model [8]. The latter flavor–asymmetry for $\Delta\bar{u}$ and $\Delta\bar{d}$ can also be studied by replacing the common constraint $\Delta\bar{u} = \Delta\bar{d} \equiv \Delta\bar{q}$ by our present Eq. (2). Using the recent analysis of [6], for example, one obtains the LO results for $\Delta\bar{u}(x, Q_0^2)$, $\Delta\bar{d}(x, Q_0^2)$ and their difference presented in Figs. 1 and 2, respectively [9]. These predictions refer to an input scale of $Q_0^2 = 1$ GeV^2 [6]. At the somewhat lower dynamical input scales $Q_0^2 = 0.3 - 0.4$ GeV^2 [3, 4, 5], the maxima/minima of the curves shown in Figs. 1 and 2 move slightly to the right, i.e. to slightly larger values of x. Strictly speaking a more consistent study of the antiquark asymmetry should be done [10] within the framework of the 'valence' scenario [4] where $\Delta s(x, Q_0^2) = \Delta\bar{s}(x, Q_0^2) = 0$. This, however, is expected to modify the present results only marginally. The NLO analysis of the polarized antiquark asymmetry [10] affords a <u>direct</u> implementation of Eq. (2) in the fit procedure due to the enhanced sensitivity of the NLO calculation of $g_1^{p,n}(x, Q^2)$ to the polarized gluon distribution which is affected by modifications of the polarized quark and antiquark distributions. Again, no qualitative changes of our present results are expected.

It is interesting to note that our results for the flavor–asymmetry of the polarized sea distributions at $Q_0^2 = 1$ GeV^2 in Figs. 1 and 2 are comparable to those obtained in chiral quark–soliton model calculations [7] and in the previously mentioned statistical parton model [8] which correctly reproduced the flavor–asymmetry of the unpolarized sea [11, 8]!

A further <u>direct</u> test of our phenomenological ansatz (2) must await the polarized version [12] of the Drell–Yan $\mu^+\mu^-$ pair production experiments [13] which provided the information on the flavor–asymmetry of the unpolarized sea distributions in Eq. (1). Future polarized semi–inclusive DIS experiments at CERN (COMPASS) and DESY (HERMES) could also become relevant for measuring possible flavor–asymmetries of polarized light–quark sea distributions [14]. The statistics of present SMC [15] and HERMES [16] measurements is not sufficient for testing our expectations in Figs. 1 and 2, for

example, despite the fact that rather stringent model assumptions have been made for the analyses of these experiments in order to improve the statistical significance.

Finally it should be noted that the data select the solution of Eq. (2) which satisfies

$$\Delta q(x, Q_0^2) \, \Delta \bar{q}(x, Q_0^2) > 0 \tag{3}$$

where $q = u, d$. This can be understood as a consequence of the expected predominant pseudoscalar configuration of the quark–antiquark pairs in the nucleon sea. In fact, Eqs. (1) and (2) can be rewritten as

$$u_+ \bar{u}_+ + u_- \bar{u}_- \;=\; d_+ \bar{d}_+ + d_- \bar{d}_- \equiv f_p \tag{4}$$

$$u_+ \bar{u}_- + u_- \bar{u}_+ \;=\; d_+ \bar{d}_- + d_- \bar{d}_+ \equiv f_a \tag{5}$$

where the common helicity densities are given by $\overset{(-)}{q}_\pm = (\overset{(-)}{q} \pm \Delta\overset{(-)}{q})/2$ and, for brevity, we dropped the x–dependence everywhere. A predominant (pseudo)scalar configuration of the $(q\bar{q})$ pairs in the nucleon sea implies, via Pauli–blocking, that the aligned quark–quark configurations $q_+(q_+\bar{q}_-)$ and $q_-(q_-\bar{q}_+)$ are suppressed relatively to the antialigned $q_+(q_-\bar{q}_+)$ and $q_-(q_+\bar{q}_-)$ 'cloud' configurations, i.e. $f_p > f_a$ which yields the result in Eq. (3).

References

[1] S. Kumano, *Phys. Rep.* **303**, 183 (1998), and references therein

[2] R.D. Field and R.P. Feynman, *Phys. Rev.* **D15**, 2590 (1977)

[3] M. Glück, E. Reya, and A. Vogt, *Z. Phys.* **C67**, 433 (1995)

[4] M. Glück, E. Reya, M. Stratmann, and W. Vogelsang, *Phys. Rev.* **D53**, 4775 (1996)

[5] M. Glück, E. Reya, and A. Vogt, *Eur. Phys. J.* **C5**, 461 (1998)

[6] Y. Goto et al., AA Collab., hep–ph/0001046

[7] D. Diakonov et al., *Nucl. Phys.* **B480**, 341 (1996); *Phys. Rev.* **D56**, 4069 (1997);
   M. Wakamatsu and T. Kubota, *Phys. Rev.* **D60**, 034020 (1999);
   B. Dressler et al., Univ. Bochum report RUB-TPII-12/99 (hep–ph/9909541)

[8] R.S. Bhalerao, *Phys. Lett.* **B380**, 1 (1996); **B387**, 881 (E) (1996); talk given at the
   Int. Conf. on QNP 2000, Adelaide, Feb. 2000 (hep–ph/0003075);
   R.S. Bhalerao, N.G. Kelkar and B. Ram, *Phys. Lett.* **B476**, 285 (2000)

[9] These results were obtained from the LO parton distributions in Ref. [6] using
   $\Delta\bar{d}/\Delta\bar{u} \equiv (\Delta\bar{q} - f)/(\Delta\bar{q} + f) = (\Delta u - f)/(\Delta d + f)$ at the input scale $Q^2 = Q_0^2$, as
   obtained by keeping $\Delta q(x, Q_0^2) + \Delta\bar{q}(x, Q_0^2)$ and $\Sigma_{q=u,d}\Delta q_v(x, Q_0^2) \equiv \Sigma_q(\Delta q - \Delta\bar{q})$
   unchanged. These replacements preserve the quality of the LO fit of Ref. [6]
   (W. Vogelsang and M. Stratmann, private communication).

[10] M. Glück, E. Reya, M. Stratmann, and W. Vogelsang (work in progress)

[11] P.V. Pobylitsa et al., *Phys. Rev.* **D59**, 034024 (1998);
   B. Dressler et al., Univ. Bochum report RUB-TPII-15/98 (hep–ph/9809487);
   M. Wakamatsu, *Phys. Rev.* **D46**, 3762 (1992)

[12] S. Kumano and M. Miyama, Saga Univ. report SAGA-HE-155-99 (hep–ph/9909432);
B. Dressler et al., Univ. Bochum report RUB-TPII-13/99 (hep–ph/9910464)

[13] A. Baldit et al., NA51 Collab., *Phys. Lett.* **B332**, 244 (1994);
E.A. Hawker et al., E866 Collab., *Phys. Rev. Lett.* **80**, 3715 (1998)

[14] T. Morii and T. Yamanishi, *Phys. Rev.* **D61**, 057501 (2000)

[15] B. Adeva et al., SM Collab., *Phys. Lett.* **B420**, 180 (1998)

[16] K. Ackerstaff et al., HERMES Collab., DESY 99-048 (hep–ex/9906035)

<u>Table I.</u> The predicted flavor–asymmetry $\bar{d}(x,Q_0^2)/\bar{u}(x,Q_0^2)$ according to Eq. (1) using the GRV98 [5] distributions $u(x,Q_0^2)$ and $d(x,Q_0^2)$ at the LO– and NLO–QCD input scales $Q_0^2 \equiv \mu_{\rm LO}^2$ ($\mu_{\rm NLO}^2$) = 0.26 GeV^2 (0.4 GeV^2). The actually fitted [5] ratio $(\bar{d}/\bar{u})_{\rm fit}$ is shown as well for comparison. The NLO results are shown in parentheses.

x	0.01	0.05	0.1	0.2	0.3
$\bar{d}/\bar{u}$	1.12 (1.13)	1.25 (1.24)	1.34 (1.36)	1.64 (1.70)	2.04 (2.11)
$(\bar{d}/\bar{u})_{\rm fit}$	1.03 (1.04)	1.16 (1.19)	1.50 (1.53)	2.00 (1.84)	1.98 (1.65)

<u>Table II.</u> The predicted polarized flavor–asymmetry $\Delta\bar{d}(x,Q_0^2)/\Delta\bar{u}(x,Q_0^2)$ according to Eq. (2) using the LO AAC input distributions $\Delta u(x,Q_0^2)$ and $\Delta d(x,Q_0^2)$ at $Q_0^2 = 1$ GeV^2 [6]. The NLO results are similar. The chiral quark–soliton predictions for $\Delta\bar{d}/\Delta\bar{u}$ of Wakamatsu and Kubota [7] are shown for comparison as well which refer to a scale $Q_0^2 \simeq 0.36$ GeV^2.

	x	0.01	0.05	0.1	0.2	0.3
	AAC	1.55	1.76	1.95	2.26	2.59
$\frac{-\Delta\bar{d}}{\Delta\bar{u}}$	soliton	1.73	2.05	2.15	1.94	1.66

Figure Captions

Fig. 1 The predictions for the polarized sea distributions $\Delta\bar{u}(x,Q_0^2)$ and $\Delta\bar{d}(x,Q_0^2)$ according to Eq. (2) with the LO results for $\Delta u(x,Q_0^2)$ and $\Delta d(x,Q_0^2)$ taken from Ref. [6] at $Q_0^2 = 1$ GeV^2.

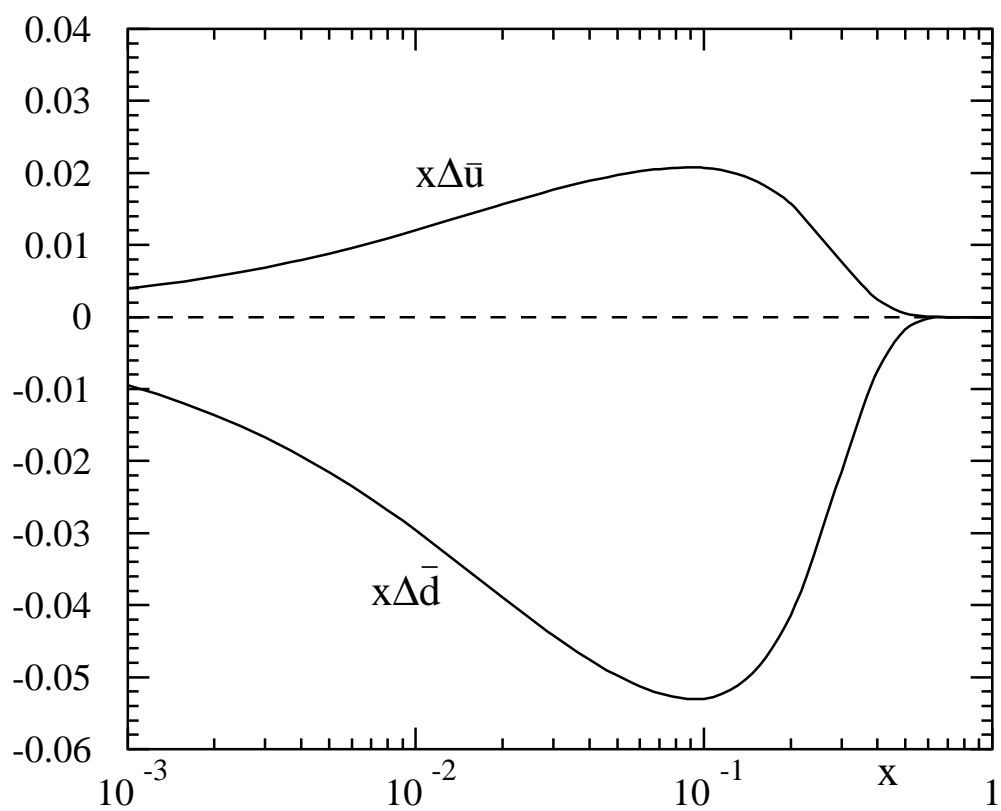**Fig. 2** The same as in Fig. 1 but for $x\Delta\bar{u}(x,Q_0^2) - x\Delta\bar{d}(x,Q_0^2)$ at $Q_0^2 = 1$ GeV^2.
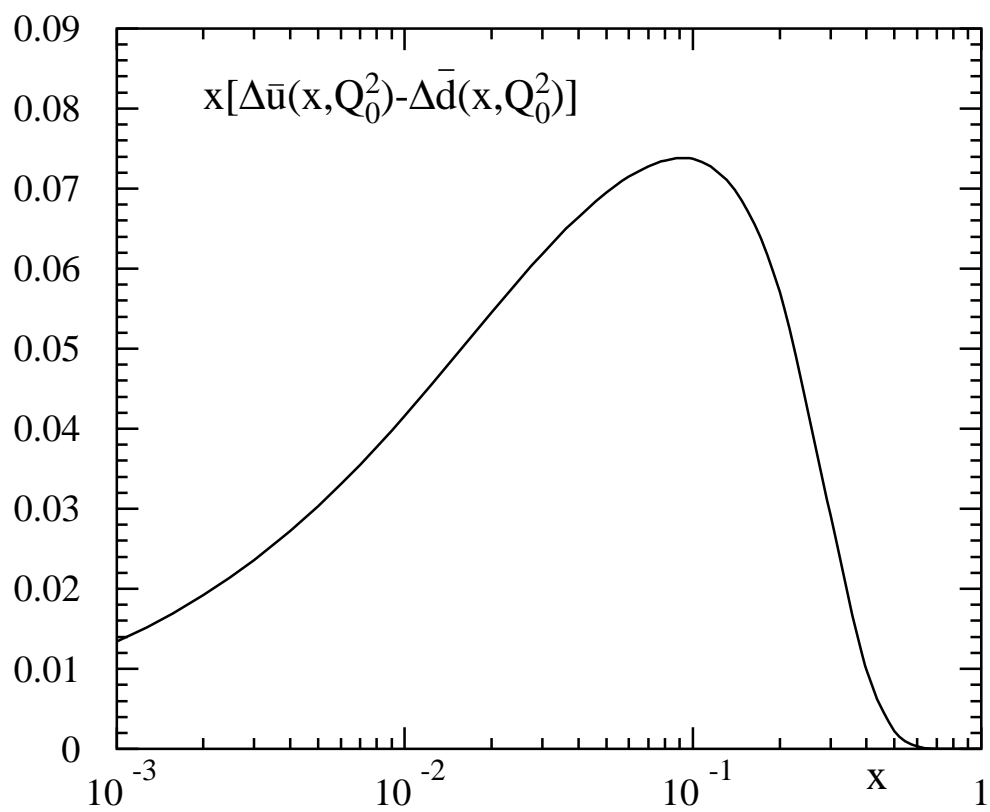
Fig. 1

Fig. 2